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AN INTERNAL COUNTER CONTROLLED LOW PRESSURE CLOUD CHAMBER

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(*Received February* 15, 1961)

ABSTRACT. A low pressure internal counter controlled cloud chamber operating at a pressure of 8 cm of Hg is described. The details of the electronic circuitry for running the chamber automatically are also presented.

I. INTRODUCTION

During the early stages of work with cloud chambers, the instrument has been operated in a random fashion. In the study of rare events as in cosmic rays and other infrequent nuclear processes, the chances that an ionizing event passes through the chamber right at the instant a random expansion is initiated being very uncertain, one has to take a prohibitively large number of photographs to get any useful information, for most of the photographs will go blank. A random mode of operation, therefore, suffers from the drawback that an investigation undertaken along such lines is very uneconomical from the point of view of the large film consumed and the long time involved. Such a situation was answered for the first time by Blackett and Occhialini (1933) who, while conducting experiments on cosmic rays, evolved a new technique in which the release mechanism of the expansion cloud chamber is actuated only in the event of an ionizing particle traversing through the chamber. The technique is well known An array of Geiger counters is placed external to the cloud chamber at the top and bottom and when the charged particle under consideration traverses through all the three constituents of the assembly, the electronic counter circuits give rise to a triggering pulse within a few microseconds of the travel of the chamber by the desired ionizing particle which releases the expansion mechanism and puts a series of other electronic controls into operation thus making it possible to have the tracks automatically photographed. The vast improvement in efficiency achieved by working the cloud chamber in conjunction with Geiger counters has made this arrangement a standard practice with all present day cloud chambers which are known as counter controlled cloud chamber''.

But in the investigations of low energy particles produced within the chamber, the control arrangement with the aid of external counters would be of little avail, since the particles with their short ranges are absorbed within the walls of the chamber itself, thereby preventing the particles from reaching the counters placed outside. Under such circumstances, it would, therefore, be an appropriate choice to place the counter inside the chamber itself. Bridge *et al.* (1948) and Leighton *et al.* (1949) have tried to work with thin-walled ion chambers and Geiger counters in the sensitive volume of the chamber. But even with the conventional counters placed inside the cloud chamber, the particle could still get bsorbed aby the cathode of the counter which normally is a hollow thin copper cylinder sealed within a glass envelope. This difficulty was overcome by Hodson and Loria (1950) who first succeeded in controlling a cloud chamber by using an "open counter" in which the cathode consisted of a cylindrical arrangement of thin rods or wires, instead of the usual metal tube. Thus by using wire electrodes which defined the cathode configuration of the counter inside the chamber, it was possible to make the counter volume a part of the sensitive region of the chamber and there was no material except the filling gas itself to retard the motion of the low energy particles. They operated the cloud chamber and consequently the counter at a pressure of 1.5 atmospheres and the filling mixture used was argon saturated with ethyl alcohol vapour.

In the present work, the technique of internal counter controlled operation has been extended to very low pressures. This paper includes details of the electronic sequence circuitry for running the cloud chamber automatically, together with some preliminary results testing the working of the instrument.

II. EXPERIMENTAL ARRANGEMENT

When an ionizing event takes place within the cloud chamber, the gas inside is ionized and the electron component of the ionized gas is collected by the central wire of the proportional counter operated within the chamber at a positive high potential. The electronic counter circuits thus give rise to a triggering voltage pulse and this pulse is used to set off a sequence of events so as to make a photographic record of the tracks of the charged particles automatically.

Fig. 1 presents the block diagram of the electronic timing circuit for the expansion chamber. The events take the following sequence :

1. The counter pulses are passed through a preamplifier and then suitably amplified by means of a high gain amplifier.
2. The pulses are admitted into a discriminator circuit where pulses due to the desired events can be discriminated.
3. The discriminated pulse is employed to run a high voltage quenching circuit which removes the high voltage on the counter before the positive ions along the path of the incident particle have had time to move any appreciable distance and the track is therefore visible and undistorted even within the sensitive volume of the counter.

4. The same pulse after discrimination is utilised to open the expansion valve which goes to complete the expansion of the cloud chamber.

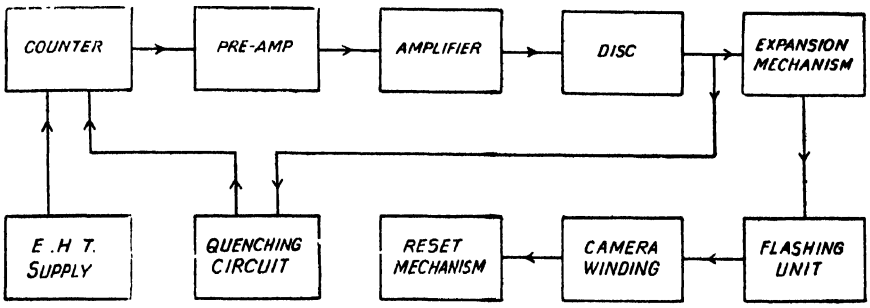

Fig. 1. Block diagram for automatic operation of the cloud chamber.

5. The flashing units are fired after a suitable delay to illuminate the tracks of droplets formed and the camera catches the photograph of the event.

6. The camera automatically winds up providing fresh film for a subsequent event.

7. The pressure in the back chamber, thereby expansion ratio, in the meantime, is automatically adjusted and the chamber kept ready for another expansion.

III. CONSTRUCTIONAL DETAILS OF THE COUNTER

The counter is mounted across the middle of the cloud chamber, the details of which have been published elsewhere (Rama Rao, 1961). The counter is 20 cms in length and 3.0 cms in diameter. The cathode assembly of the counter is defined by four rods 1 mm in diameter supported at the ends by copper rings. The anode is a 3 mil tungsten wire stretched axially with respect to the cylinder defined by the cathode assembly. The cathode supporting rings are fitted with perspex discs. To one end of the anode wire a glass bead is fused and held against a small hole at the centre of the perspex disc. The other end of the wire is taken through the centre of the perspex disc facing the previous one and is fused into a brass screw and the wire is kept straight by applying suitable tension and tightening the nut against the perspex disc. Proper care is taken to prevent any twisting of the wire while fixing up. A connecting lead is soldered to the screw and brought out through a narrow drill hole in the wall of the perspex chamber. The chamber is made leak tight at this point by applying transparent glyptal. The whole counter assembly is mounted on two rigid supports made of copper that take the form of brackets bent in the form of a right angle and screwed on firmly to the metallic flange of the chamber. Thus the cathode of the counter is kept at the ground potential by grounding the metallic casing of the cloud chamber. The details of mounting the counter within the chamber are shown in Figs. 2 and 2a.

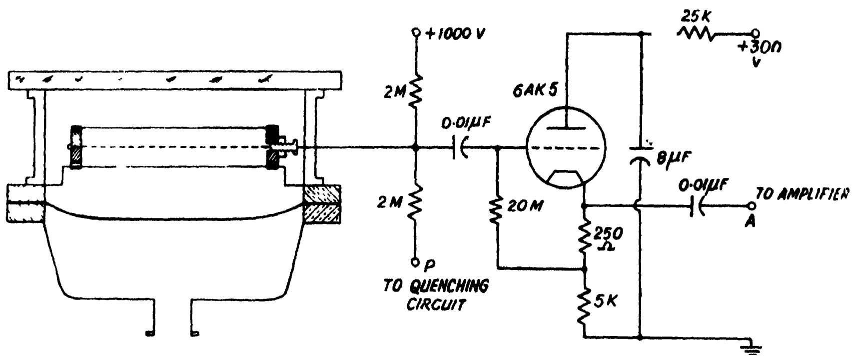

Fig. 2. Counter mounting within the chamber and cathode follower pre-amplifier.

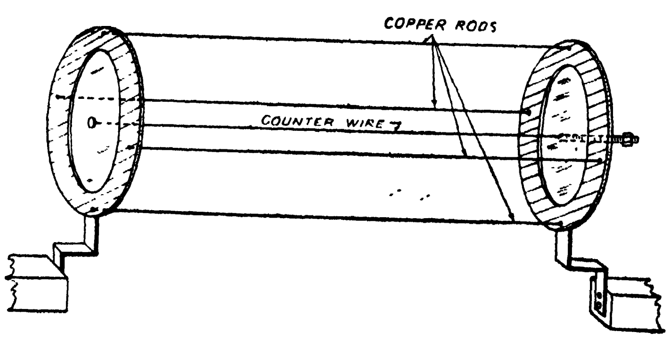

Fig. 2a. Perspective view of the counter.

IV. CHOICE OF GAS-VAPOUR FILLING

In the present set-up, the proportional counter which is incorporated within the cloud chamber is not isolated from the chamber volume by glass envelope whatsoever, but forms a part of the sensitive region of the chamber itself. Such being the case, the choice of the gas-vapour mixture filling the chamber comes up as a major consideration. The same gas-vapour composition must play the dual role of a satisfactory cloud chamber filling mixture for obtaining good tracks and at the same time a satisfactory filling for operating the counter in the proportional region.

When an ionizing particle moves through the gas of the counter, it gives rise to a number of electrons and an equal number of positive ions along its track. The electrons created by the primary ionizing particle can be drawn towards the anode which is maintained at a positive potential. If the attractive voltage acting on the electrons is suitably adjusted, the electrons can be drawn into the near vicinity of the wire and there they enter a region in which the field strength rapidly increases in magnitude. Thus in traversing through a short distance, the electrons originally produced along the track now acquire between collisions with atoms and molecules sufficient kinetic energy to result in further multiplication of ions due to secondaries which remain proportional to the initial ionization as long as the counter is operated in the proportional region. It can thus be seen that such gas multiplication is possible only when the electrons remain freely mobile and the gas-vapour composition does not exhibit appreciable electron affinity. For this reason, oxygen and water vapour both of which have great affinity for electron attachment had to be excluded from the chamber filling. A filling of commercial argon (99.8% purity, oxygen-free) and isoamyl alcohol has been found to be a satisfactory mixture for operating the chamber in the region of 5 cms of Hg. Detailed investigations on the choice of gas-vapour composition had been undertaken and the results were communicated in an earlier paper (Rama Rao, 1961). The same composition is now found to go well with the counter operating in the proportional region.

V. INTERNAL COUNTER OPERATION FOR EXPANDING THE CLOUD CHAMBER

The anode of the counter is operated at a positive high potential while the cathode rods are earthed. When an ionizing particle passes through the cloud chamber and therefore the counter, the gas inside is ionized leaving positive ions and electrons. Since pure argon has been used as the permanent gas in the cloud chamber, there is very little tendency for the electrons to attach themselves to the gas molecules to form negative ions. Thus all the electrons are now accelerated towards the central anode wire of the counter and get collected there. The negative pulse collected by the wire is amplified by a high gain linear amplifier and is utilised in bringing about the expansion of the cloud chamber.

The collection of electrons by the counter is completed within an interval of a few microseconds. It is known that the mobility of electrons is much higher than that of the heavier ions. This leads to the advantage that if the voltage pulse due to the electron collection triggers the expansion of the cloud chamber, the slow positive ions, which have not had time to diffuse to any appreciable extent, would act as condensation nuclei for the vapour and enable to obtain a photograph of the tracks that are responsible for triggering the chamber.

The present counter with its dimensions mentioned earlier has a suitable proportional region over the range 850-1000 volts when operated at pressures of 8 cms of Hg. With this set of operating conditions it has been found possible to reproduce the pulse sizes in the counter over a period of 2 to 3 days. Thereafter, the pulse size diminished steadily owing to change in the composition of the gas-vapour mixture as a result of slow diffusion of air into the chamber through the rubber gaskets and also due to release of oxygen and moisture from the walls of the perspex chamber. It was thus found necessary to exhaust the chamber once in 3 days and refill the chamber to have a reproducible counter performance.

VI. ELECTRONIC CIRCUITRY FOR COUNTER OPERATION OF THE CLOUD CHAMBER

It is proposed to discuss here in some details the functions and performance of the different electronic circuits used in the operation of the instrument.

a) *Amplifier and Discriminator*

The negative pulses from the anode of the counter are taken through a cathode follower pre-amplifier to the main amplifier. The pre-amplifier (Fig. 2) is placed close to the counter and this is necessary because the grid of the input stage must be as close as possible to the electrical detector in order to keep capacitance at a minimum. Shielded cables of short lengths have been used to carry the pulses from the counter to the input of the pre-amplifier. The output from the pre-amplifier is fed to the input stage of the main amplifier at the point A.

The pulse amplifier used (Fig. 3) has two three-tube feed back loops each with a gain of 100. Thus the total gain is 10^4 and can be varied by means of coarse

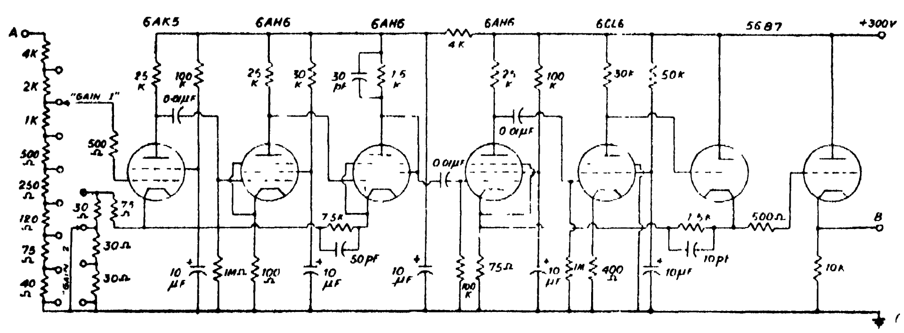

Fig. 3. Amplifier.

and fine controls. The measured band width of the amplifier is roughly 1 cm. It is identical with Model 100 pulse amplifier described by Elmore and Sands (1949) with the exception that equivalent miniature tubes have been used to derive the advantages of their low interelectrode capacitances. Shielded coaxial cables have been used to carry the pulses from the pre-amplifier to the input of the main amplifier and sufficient care has been taken to shield the amplifier adequately in order to avoid pick-up of transient electrical disturbances.

The positive output pulses from the amplifier are taken through a cathode follower and are fed at the point B to drive a voltage discriminator circuit (Fig. 4).

The bias voltage of the discriminator is adjusted by setting the potentiometer so that the circuit triggers for input pulses of pre-determined amplitudes. Output pulses of approximately 80 volts amplitude are taken from the plate of the second tube of the discriminator and are used to drive the voltage quenching circuit and the sequence circuit.

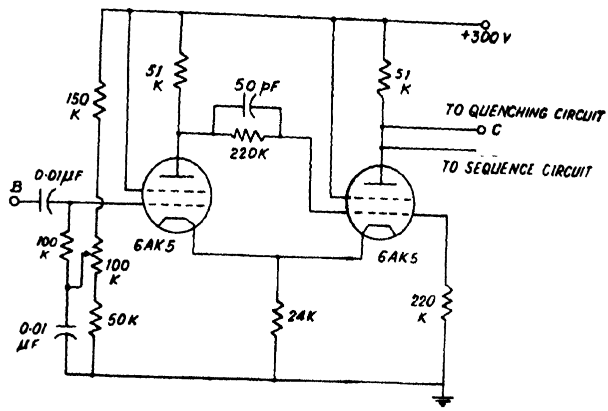

Fig. 4. Discriminator circuit.

b) *High voltage quenching circuit*

It is necessary to remove the high voltage on the proportional counter as soon after the collection of the electron component of the ionization event as possible so that the positive ions have had little time to disperse in the gas medium under the action of the strong electric field in the vicinity of the counter, which other-wise would result in broadening and distortion of the tracks. A portion of the track is also lost in the sensitive volume of the counter. The lowering of voltage on the counter much below the operating point is achieved by using a quenching circuit in the voltage supply of the proportional counter.

The operation of the voltage quenching circuit is explained with reference to Fig. 5 and Fig. 2. The discriminator pulse is taken to point C of the voltage

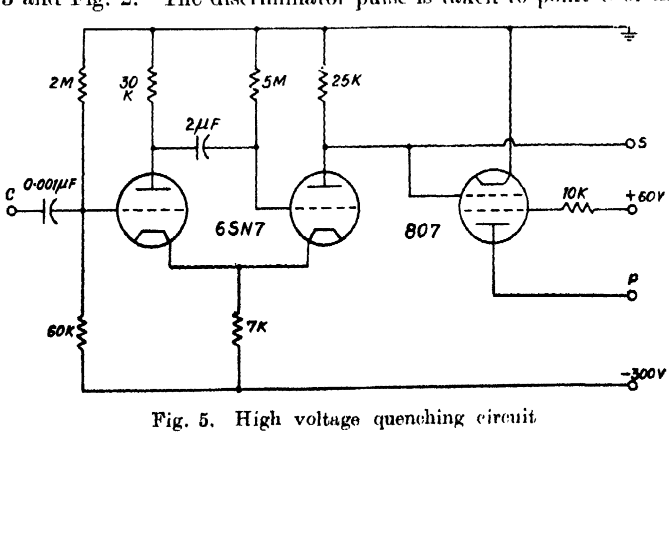

Fig. 5. High voltage quenching circuit

quenching circuit which is composed of a cathode coupled multivibrator circuit and a 'voltage quenching tube'. Type 6SN7 tube is used for the multivibrator part of the circuit and type 807 is the quenching tube. The plate point of 807 is tied to the anode of the counter through a 2MΩ resistor. The plate point of the conducting half of 6SN7 is connected to the grid of 807 tube so that the grid of 807 is maintained at a high negative potential with respect to the cathode and the tube does not draw any current. Therefore, at the start the full voltage applied on the counter also resides on the plate of 807. Now when the multivibrator circuit is triggered by the incoming pulse, the conducting section of 6SN7 tube becomes non-conducting and the grid of 807 is raised to zero potential. The 807 tube now conducts and there is a voltage drop across the plate load of 807 which is experienced by the counter anode. The voltage on the counter is thus lowered from a positive high voltage to a few volts in a very short interval of time and the voltage on the counter remains lowered until the multivibrator recovers to its normal state, determined by the CR value of the circuit which is of the order of a few seconds. By suitably adjusting this delay, the voltage on the counter has been kept lowered until the cloud chamber expansion is completed and photographs of tracks have been obtained.

(c) *Sequence control circuit*

The sequence circuit (Fig. 6) includes the chamber expansion device and other auxiliary time sequence control circuits for the flashing of lamps, winding the camera, and resetting the chamber after every cycle of operation.

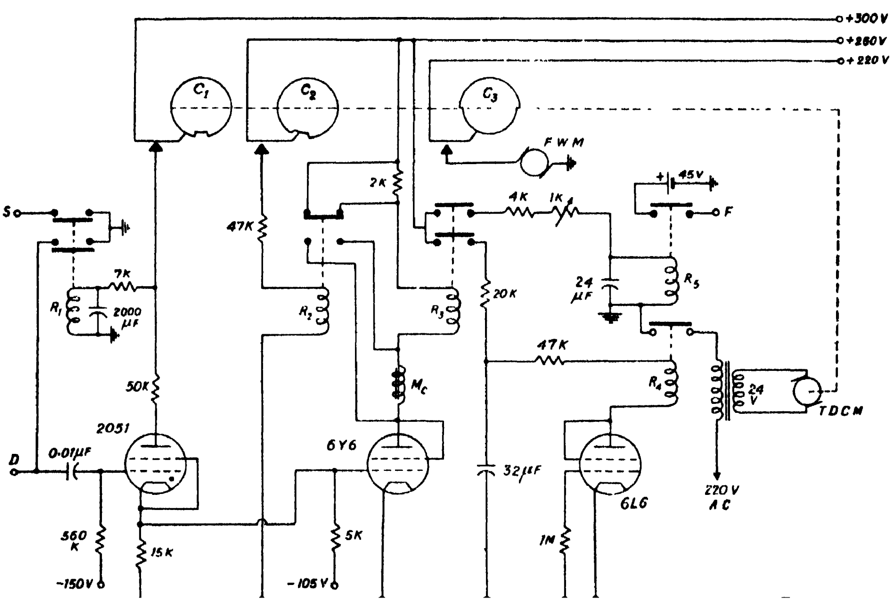

Fig. 6. Timing sequence circuit.

The magnet coil M_e of the high vacuum magnetic valve which brings about the expansion of the chamber is included in the plate circuit of 6Y6 tube. The magnet is of the type that normally remains closed under gravity. The grid bias on 6Y6 tube is initially maintained sufficiently negative such that the tube does not conduct and hence the magnet is not energized. The grid of 6Y6 tube is tied to the cathode point of the thyratron tube 2051. When the voltage pulse from the discriminator is fed to the grid of 2051, the tube fires and the voltage developed across the cathode resistor of 2051 raises the grid potential of 6Y6 to zero volt and makes 6Y6 conducting. The plate draws current and the magnet coil is energized, thus opening the magnet valve so as to expand the chamber.

R_3 is a relay operating in series with the magnet coil. Normally the relay is in the off-position and is energized along with the magnet coil of the main expansion magnet. With the help of relay R_3, two circuits are operated with suitable delays introduced in their paths. The circuit operated from one set of contact points is intended for running flashing units and the one from the other set drives a time delay cam motor (T.D.C.M.).

The action of T.D.C.M. can be understood as follows : When the relay R_3 is energized, H.T. is supplied to the plate of 6L6 thus making it conducting. The relay R_4 which is in the plate circuit is now energized and the primary circuit of the transformer which is connected across the contact points of this relay is completed. A 24 volt motor is operated from the secondary of the transformer and the speed of the motor is cut down by suitable reduction gear system. Cams C_1, C_2, C_3 are mounted axially on the shaft of the motor. The cams are made of small circular perspex discs. Shallow slots of varying widths are cut on the periphery of these discs. Three contact switches are mounted on an insulated base plate close to the discs such that the switches sweep out the periphery of the perspex discs as the motor shaft carrying these discs begins to rotate. When one of the prongs of the switches falls into the slot, the contact breaks and the corresponding circuit operated by this particular switch is disconnected. Thus the elevated portions on the three cams determine the time scale for which a particular circuit is held in operation. A magnified picture of the time delay cams is presented in Fig. 7.

When once the thyratron is fired and the sequence circuit is put into operation, the cam begins to rotate until the switch on cam C_1 interrupts the plate voltage of the thyratron tube. The time for a complete revolution is set at 3 minutes and this gives the operation cycle of the cloud chamber. It can thus be seen that the magnet coil of the expansion magnet also remains energized for the whole time the thyratron is in the conducting state. But we wish to return the magnet valve to its normal condition as soon after photography of the ionizing event as possible so as to isolate the back chamber from the vacuum ballast and raise the pressure in the back chamber to the present value by admitting air through an auxiliary air admittance valve, details of which have been described in an earlier paper (Rama Rao, 1961). The magnet valve is returned to its normal position

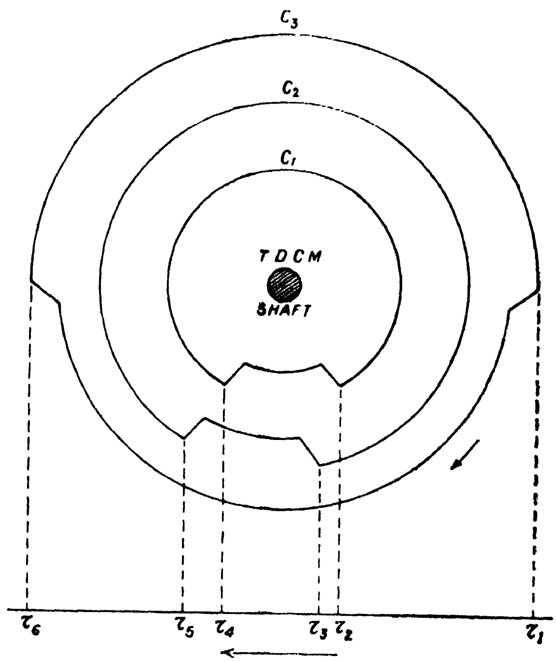

Fig. 7. Magnified diagram of the time delay cams.

by short circuiting the magnet coil. This is done with the help of relay R_2 which operates through the contact switch mounted on Cam C_2. The slot on cam C_2 is slightly displaced with respect to the one on cam C_1 so that as the cam rotates the switch on cam C_2 comes into operation a little while after the expansion is complete. As soon as the relay R_2 is pulled down, the magnet coil is short circuited thus shutting the valve and a 2K resistance appears in series with the relay coil R_3 keeping the total plate load of 6Y6 unaltered. The magnet coil is thus short circuited for the complete cycle, as long as the contact switch on C_2 is closed which is released only after the contact switch on C_1 is opened.

d) *Flashing circuit*

The tracks of ionizing particles are photographed under strong illumination which lasts momentarily. The illumination is provided by two Mazda flashing lamps F.A.2 with a rating of 2500 VDC and 500 joules dissipation. The circuit for operating these tubes is showing in Fig. 8.

Along with the expansion of the magnet, the relay R_3 is energized and through one set of contact points of the relay R_3 voltage is applied to the relay R_5 which is energized after a delay determined by the CR value in the circuit. Closing of the relay contacts gives rise to a positive pulse from a battery of 45 volts which is fed to the point F to trigger a cathode coupled multivibrator (Fig. 8). The negative rectangular pulse taken from the plate of the first half of 6SN7 tube is dif-

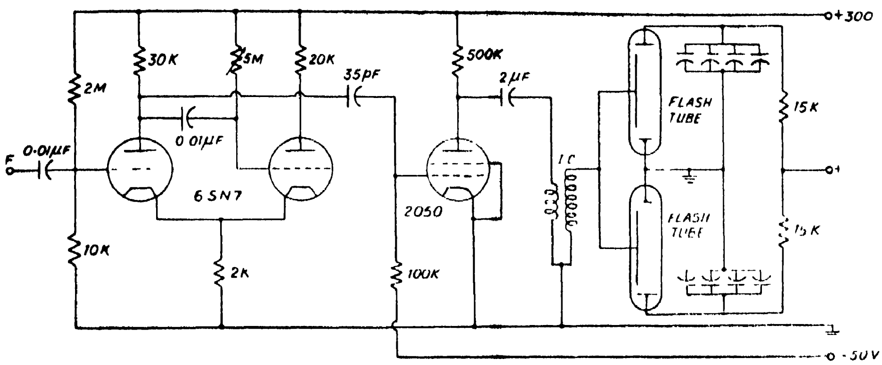

Fig. 8. Flashing unit.

ferentiated by the 35pf and 100KΩ net work. The positive spike of the differentiated pulse is utilized to fire the thyratron tube 2050. The triggering action of 2050 can be delayed with respect to the input pulse at F by 5 MΩ potentiometer. When the switching action of the thyratron takes place, a 2μf condenser which is previously charged to 300V is now discharged producing a current surge in the primary of the Ignition coil (I.C.). The high voltage pulse developed across the secondary which is of the order of several KV is applied to the trigger electrode of the flash tubes. Two banks of condensers, each 64μf, connected across the flash lamps and charged to 1500 volts D.C., get discharged through the tubes owing to the breakdown of the gap between the electrodes as a result of the sudden rise in the electric field and thus an intense burst of light is obtained.

e) *Photography and film winding*

The camera for taking stereoscopic pictures is mounted vertically above the cloud chamber. The camera is of the open shutter type and hence the cloud chamber had to be operated in a dark room.

After the event has been photographed, the film is wound up and set ready for the next photograph. This is done by a slow motion motor (F.W.M.) which is kept in motion by the operation of the contact switch on cam C_3. The time for which the motor is running to wind up the exposed portion of the film is determined by the length of the slot on the cam C_3.

f) *Reset mechanism*

When once the thyratron of the sequence circuit is fired and the sequence circuit put into operation, the grid loses its control on the performance of 2051 tube and the tube remains conducting and consequently the associated circuits on, until the switch on cam C_1 interrupts the plate voltage on 2051. As the cam rotates after a complete cycle of operations of the sequence when the slotted portion faces the switch on C_1, the voltage on 2051 is removed, rendering it non-conducting and thus the rest of the circuit is thrown out of action. The circuit has to be set ready for a subsequent operation by restoring the voltage on the plate of 2051. This is achieved as follows :

As soon as the switch contact on cam C_1 is broken, 2051 is extinguished and hence 6Y6 becomes non-conducting, de-energising the relay R_3. Though the plate supply for 6L6 tube which it gets through the relay contacts of R_3 is cut off, the charge accumulated by the $32\mu f$ condenser supplies the voltage for the relay coil R_5 and holds it in the on-position and consequently the T.D.C. motor running. This continued operation of the motor for a little while after the main source of supply voltage is cut off overshoots the slotted portion of the cam C_1 so that the contact of the switch on C_1 is re-established and occupies the position indicated in (Fig. 6). The plate voltage on 2051 is thus restored and the tube is ready for triggering on the arrival of a fresh pulse at the grid of the tube.

g) *Spurious operation of the chamber*

It was occasionally detected in a few blank operations that at the time of establishing the switch contact on cam C_1 after a complete cycle of operations, due to faulty contact, a spark at the contact point was a source of disturbance which after having been picked up and amplified is fed to the grid of 2051, thus driving the circuit and giving a fake expansion without a real pulse from the counter being fed.

This was avoided by cleaning the contacts regularly and also by ensuing smooth contacts by adjusting the gap between the contact points. Additional precaution was taken to ground the grid of 2051 during the time the switch contact was being established. This can be understood by referring to the operation of relay R_1 in (Fig. 6). When the contact switch is in the slotted portion of cam C_1, the relay R_1 is disengaged and the input to the grid of 2051 is grounded through a pair of contact points of relay R_1. When the contact switch on cam C_1 is being pulled out of the slot and voltage on plate of 2051 restored, the relay R_1 is energized but slowly owing to the high value of the capacitor, $2000\mu f$, thus the grounding of the input to 2051 is released only after firm contact of the C_1 cam-switch is established.

For the time the grid of 2051 is grounded, the grid of 807 tube is also kept at ground potential by connecting the grid of 807 at the contact point S of relay R_1. This brings about the removal of voltage on the counter once again thereby avoiding the production of fresh ionization by discharges in the counter.

VII. RESULTS AND DISCUSSION

A preliminary testing of the set-up has been made by initiating the expansion of the cloud chamber using α-pulses picked up by the counter. Fig. 9 shows a photograph of α-tracks obtained at 8 cm of Hg.

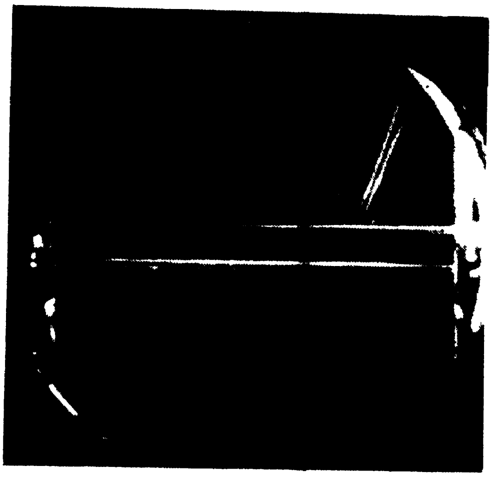

Fig. 9. Photograph of α-tracks obtained at 8 cms of Hg using argon and iso amayl alcohol as filling mixture

It may be mentioned here that the quality of tracks mainly depends upon the diffusion of ions. The width of the track is a function of the speed of expansion which is defined as the time elapsed between the moment the particle passes through the counter and the achievement of the expansion of the chamber. The time taken by the magnet to open fully is the predominant factor for obtaining sharp tracks as the delays introduced in the electronic circuit being of negligible order. The magnetic valve used in the present experiment is a high speed expansion valve and a rough estimate shows that it is of the order 5 m.sec.

ACKNOWLEDGMENTS

The author is indebted to Prof. B. D. Nag Chaudhuri, Director of the Institute, for his constant guidance and encouragement. The author is grateful to Prof. D. N. Kundu for his keen interest and valuable discussions.

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